MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EME4026 – TRIBOLOGY

(ME)

7 MARCH 2020
9:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENT

1. This Question paper consists of 10 pages including cover page with **4 Questions** only.
2. Attempt **FOUR** out of **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.
4. A list of useful equations and charts are given as **Appendix A**.

Question 1

(a) **Explain** and illustrate the four mechanisms involved in ploughing friction.

[12 marks]

(b) A hard conical asperity of roughness angle 13° is scratched along a soft flat surface to produce a groove of 0.8 mm width. The measured coefficient of friction is 0.27. **Determine** the abrasive and adhesive component of friction coefficient and the groove depth.

[13 marks]

Question 2

In a pin-on-disc wear experiment, the flat face of a brass annulus pin having an outside diameter of 20 mm and inside diameter of 10 mm is rubbed on a flat steel disc of diameter 120 mm at a distance of 40 mm away from their centers. The test conditions and wear results are given as follows:

Normal load = 20 N
Rotational speed of the disc = 90 rpm
Sliding duration = 120 hours
Hardness of brass = 0.8 Gpa
Hardness of steel = 2.5 Gpa
Density of brass = 8.5 Mg/m^3
Density of steel = 7.8 Mg/m^3
Mass loss of brass = 40 mg
Mass loss of steel = 2 mg

i. **Sketch** the wear track on the disc and **determine** the sliding distance.

[9 marks]

ii. **Determine** the adhesive wear coefficients for both materials.

[8 marks]

iii. **Calculate** wear depths of the brass pin and steel disc.

[8 marks]

Continued...

Question 3

(a) **State** four causes of waviness in a surface. **[4 marks]**

(b) A hydrodynamic bearing with *L/D* ratio = 0.25 is designed to operate at journal speed of 1380 rpm and subject to a radial load of 2000 N. The radial clearance is 0.06 mm. Assuming SAE 10 oil is used and its operating temperature is 50°C, **determine** the following:

i. Sommerfeld number. **[4 marks]**

ii. Minimum oil film thickness, h_o. **[3 marks]**

iii. Coefficient of friction, f. **[3 marks]**

iv. Maximum film pressure, P_{max}. **[3 marks]**

v. Angle between load direction and minimum film thickness, Φ **[2 marks]**

(c) **Derive** an expression that relate Petroff's equation to Sommerfeld number.

[6 marks]

Question 4

(a) An automobile engine has five main bearings, each 2.5 inch in diameter and 1 inch long. The diametral clearance is 00015 inch. By using Petroff's equation, **estimate** the power loss per bearing at 3600 rpm if SAE 30 oil is used, with an average oil film temperature of 180°F.

[13 marks]

(b) **Explain** and show schematically the convergence wedge action in journal bearings.

[12 marks]

Continued...

Appendix A

- **Adhesion friction force** $F_a = A_r\ \tau_a$
- **Adhesion friction coefficient for dry contact:**

$$\mu_a = \frac{F_a}{W} = \frac{A_r.\tau_a}{W} = \frac{A_r.\tau_a}{P_r.A_r} = \frac{\tau_a}{P_r}$$

- **The friction coefficient in terms of surface roughness in elastic region,**

$$\mu_a \approx \frac{3.2(\tau_a)}{E^*\left(\frac{\sigma_p}{R_p}\right)^{1/2}},\quad \frac{1}{E^*} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2},\quad \sigma_p = \sqrt{\sigma_{p1}^2 + \sigma_{p2}^2},\ \text{and}\ \frac{1}{R_p} = \frac{1}{R_{p1}} + \frac{1}{R_{p2}}$$

- **Degree of plasticity.** $\varphi = (E^*/H)(\sigma_p/R_p)^{1/2}$
- **Ploughing friction due to a circular cone hard asperity**

$$\mu_p = \frac{F_f}{W} = \frac{2d}{\pi r} = \frac{2\ \tan\theta}{\pi},\quad \text{or}\quad \alpha = 90^o - \theta,\qquad \mu_p = \frac{2\ \cot\alpha}{\pi}$$

- **Ploughing friction due to a spherical hard asperity**

$$\mu_p = \frac{F_f}{W} = \frac{P_y.A_p}{P_y.A_l} = \frac{A_p}{A_l} = \frac{2}{3\pi}.\frac{2r}{R}$$

- **Ploughing friction due to a spherical asperity for a relatively large groove width as compared to sphere radius:**

$$\mu_p = \frac{2}{\pi}\left\{\left(\frac{R}{r}\right)^2 \sin^{-1}\left(\frac{r}{R}\right) - \sqrt{\left(\frac{R}{r}\right)^2 - 1}\right\}$$

- **Ploughing friction due to a cylindrical asperity:**

  Case-1: the cylindrical placed transversely over a softer surface, $\mu_p = \sqrt{\frac{1}{2(R/d)-1}}$

  Case-2: the cylindrical placed upright over a softer surface, $\mu_p = (2/\pi)\frac{d}{R}$

- **Holm equation for adhesive wear,** $V_w = \frac{k_{adh}.W.x}{H}$ *Plastic contacts*
- **Archard equation for adhesive wear,** $V_w\ \alpha\ \frac{W.x}{H} = k_{adh}\frac{W.x}{H}$ *Plastic contacts*
- **Bhushan equation for adhesive wear,** $V_w = \bar{k}_{adh}\frac{W.x}{E^*\sqrt{(\sigma_p/R_p)}}$ *elastic contacts*
- **Rabinowicz's equation for abrasive wear,** $V_w = \frac{2W.x.\tan\theta}{\pi.H}$
- **An abrasive expression similar to Archard's equation,** $V_w = \frac{K_{abr}.W.x}{H}$

Continued...

Petroff's Equation

Friction torque $$T_f = \frac{4\pi^2 . \eta . n . L . R^3}{C} = f . W . R = f (D . L . P) R$$

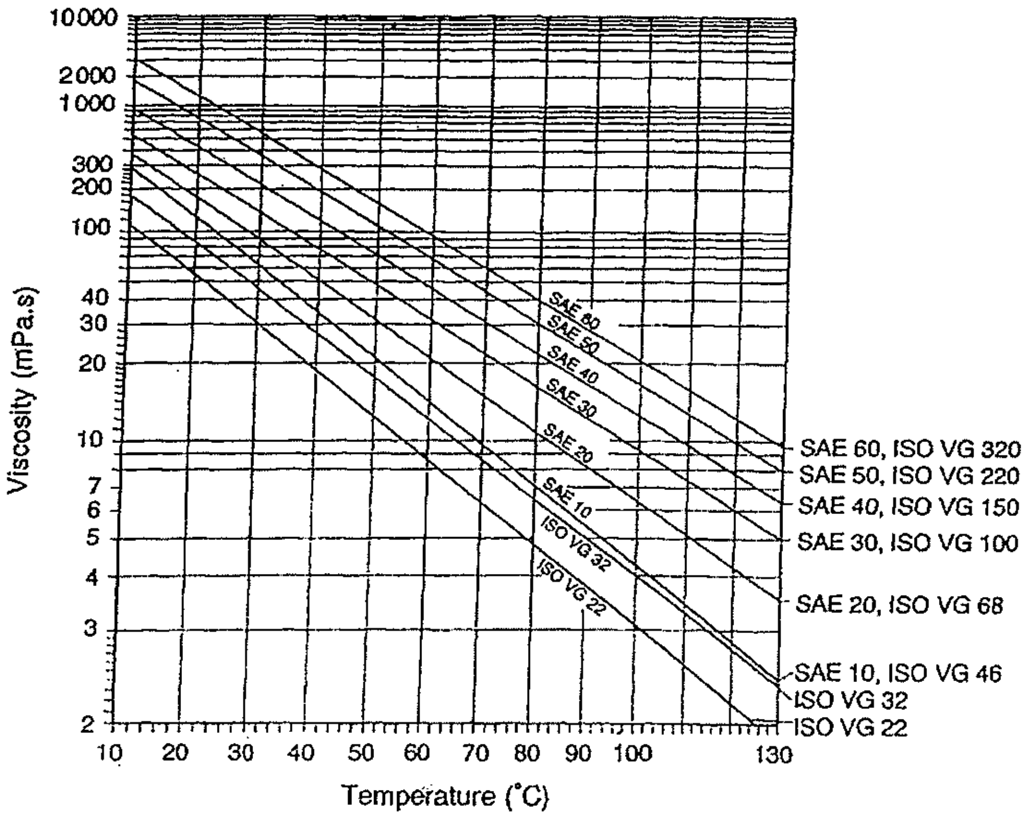
Coefficient of friction $$f = 2\pi^2 \left(\frac{\eta\, n}{P}\right) . \left(\frac{R}{C}\right)$$

Power loss (watt) $$H_v = 2\pi . T_{f\,(N.m)} . n_{rps}$$

Sommerfeld number $$S = \left(\frac{R}{C}\right)^2 \frac{\mu\, n}{P}$$

Average film pressure $$P = \frac{W}{DL}$$

Chart A1 – Variation of absolute viscosity with temperature for various lubricants



Continued...

Chart A2 – Viscosity versus temperature curves for typical SAE graded oil

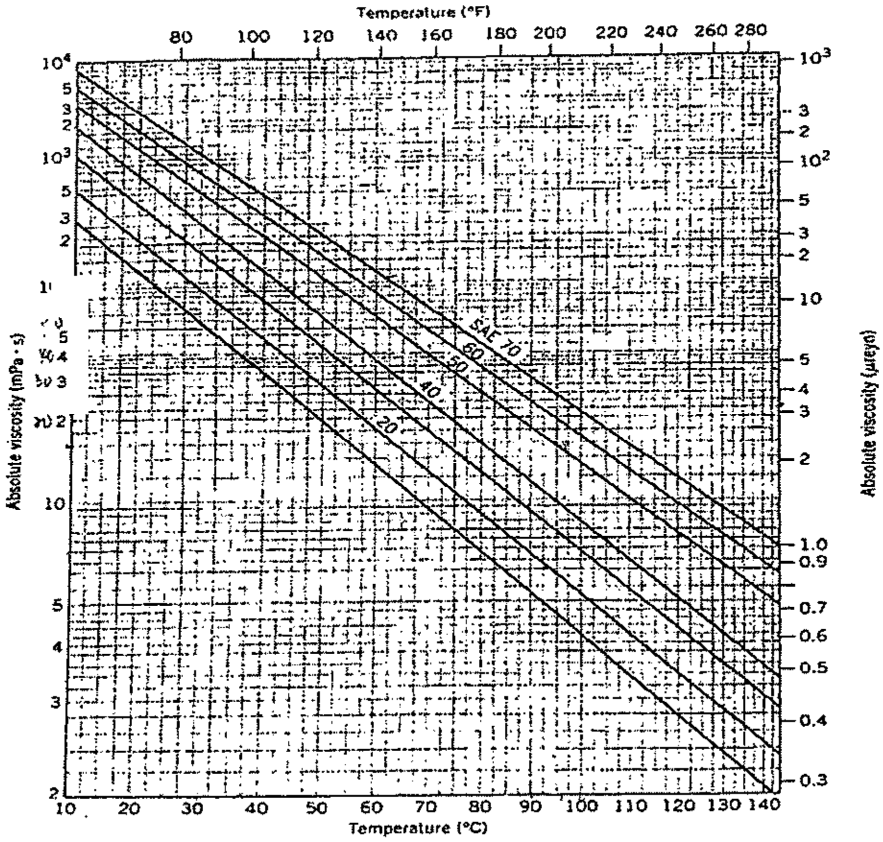
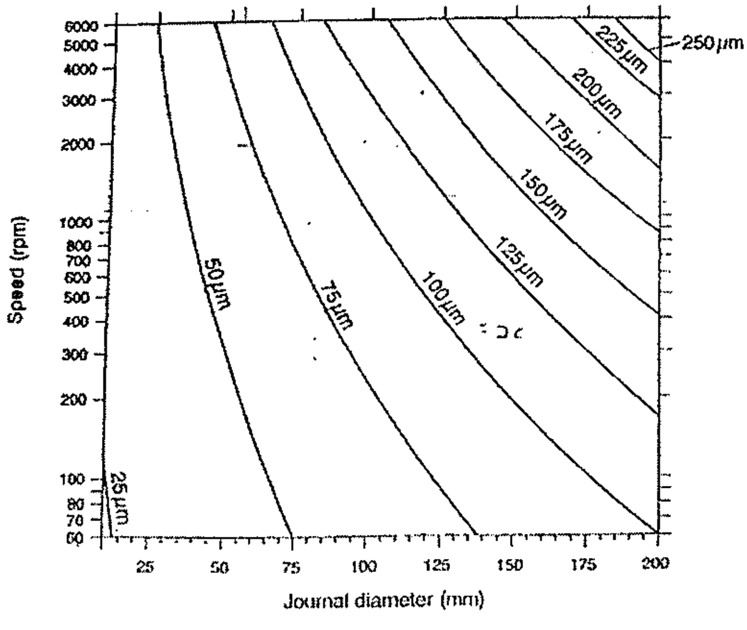
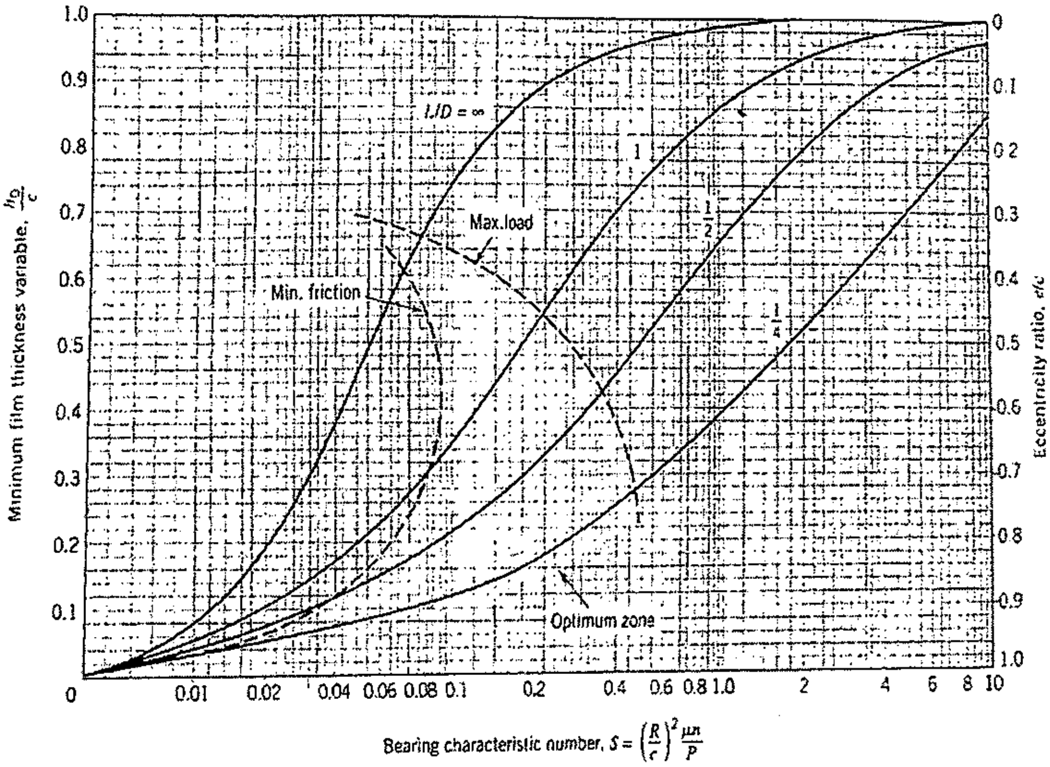


Chart A3 – Recommended values of diametral clearance (2c) for steadily loaded journal bearing



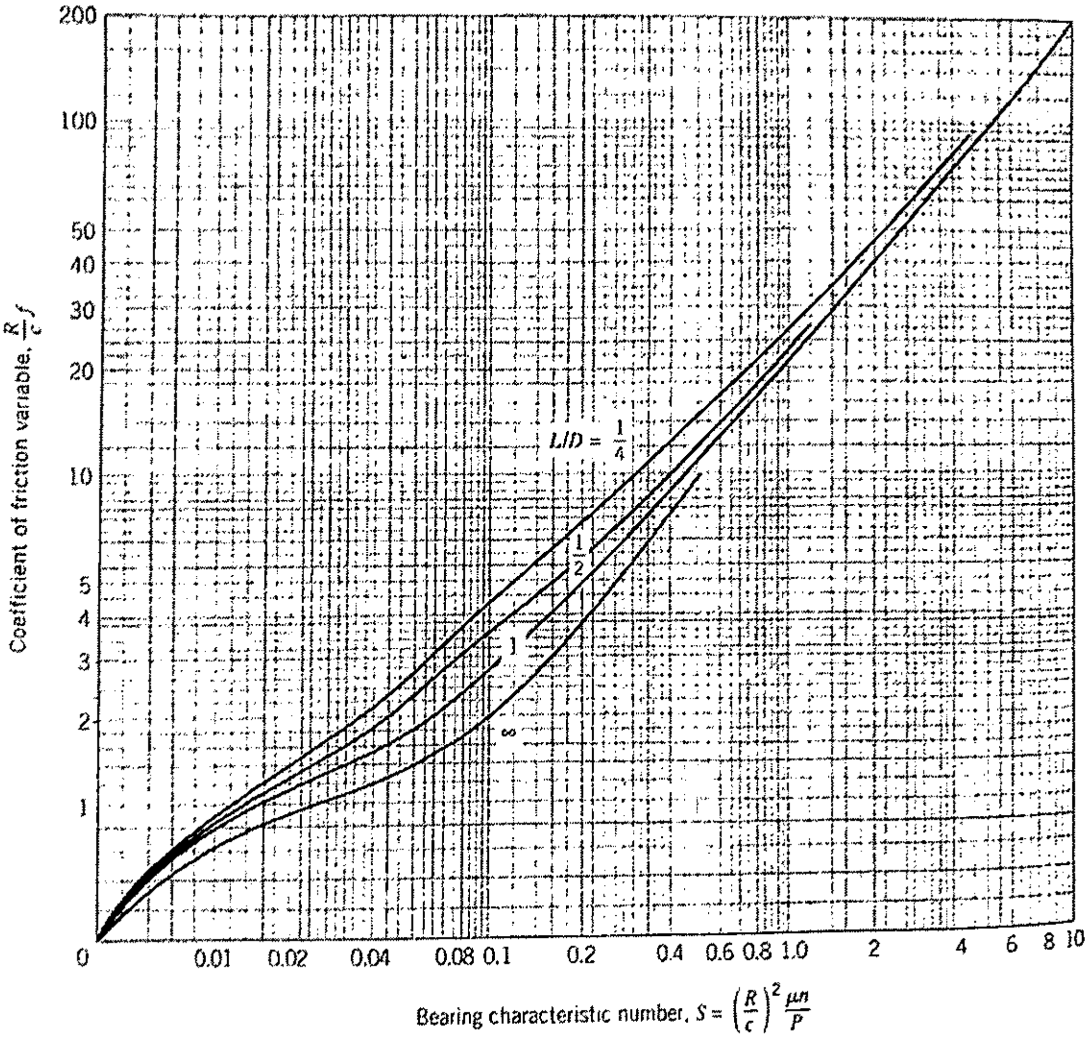
Continued...

Chart A4 – Minimum film thickness variable



Continued…

Chart A5 – Friction coefficient variable



Continued...

Chart A6 – Maximum film pressure

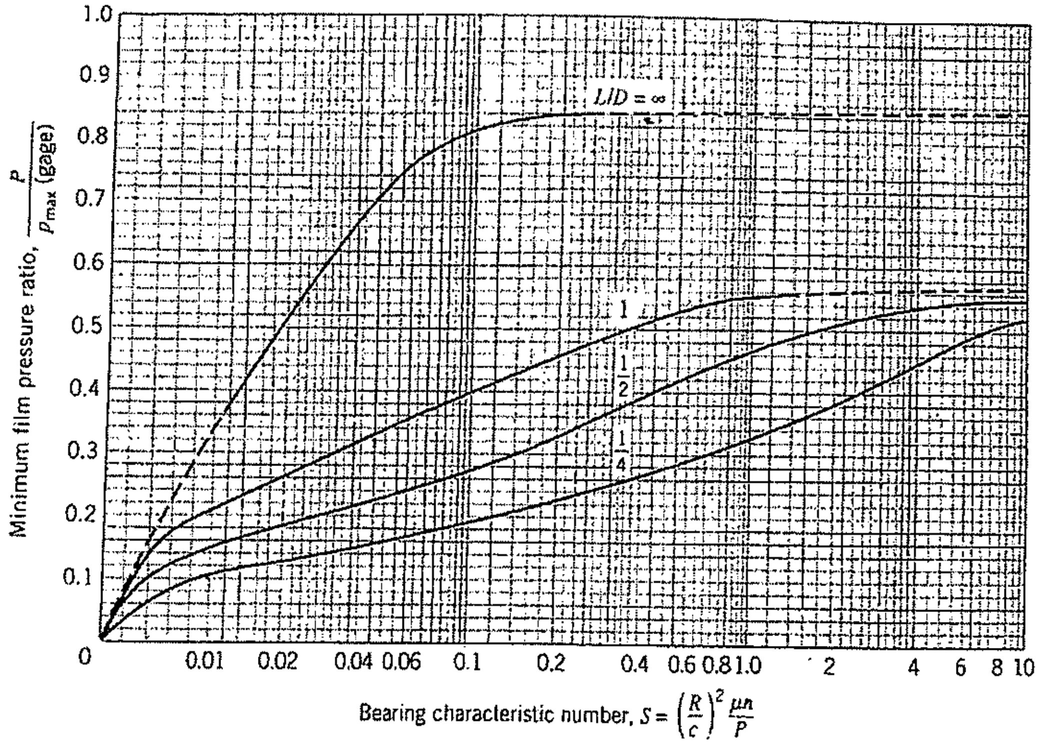
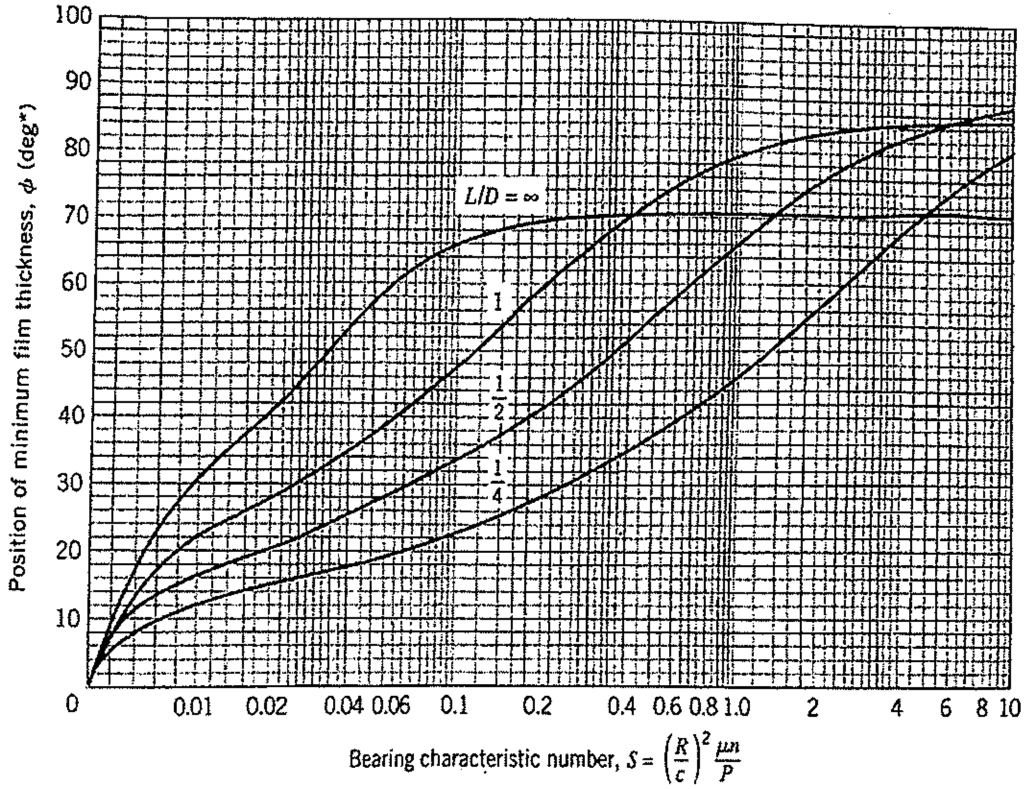
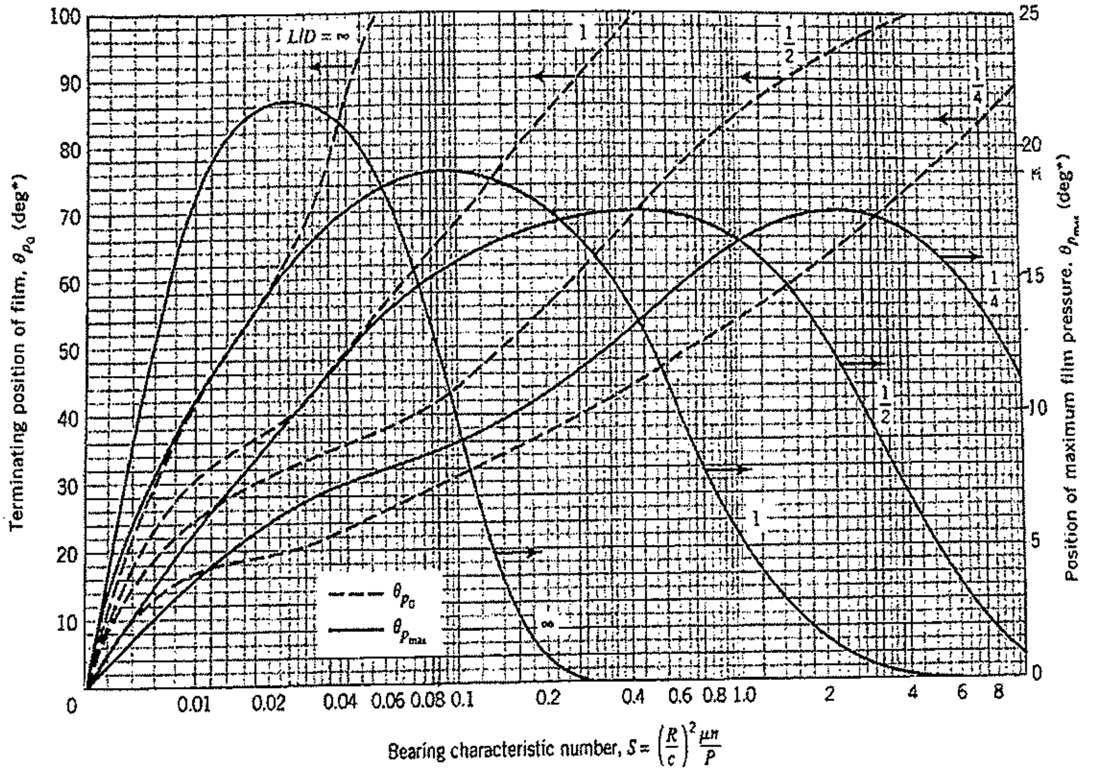


Chart A7 – Position of the minimum film thickness



Continued…

Chart A8 – Positions of the maximum film pressure and film termination



End of Paper